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Michael D. Dzandu & Buddhi Pathak

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Diy laboratories, their practices, and challenges – a systematic literature review

Michael D. Dzandu [a] and Buddhi Pathak [b]

[a]Centre for Digital Business Research, Westminster Business School, University of Westminster, London, UK; [b]Bristol Business School, University of West of England, Bristol, UK

ABSTRACT

The last two decades have seen a growing literature worldwide on do-it-yourself (DiY) laboratories driving informal innovation. However, there is a limited account of the state-of-the-art DiY literature to the emergence of DiY laboratories or of the challenges, strategies for its diffusion and success. This study, therefore, aims to understand the state-of-the-art of DiY laboratories. Using the systematic literature review approach, 29 articles are analysed. The results revealed that the main purpose of publications on DiY laboratories was geared towards showcasing informal innovation. Most of the studies used the case study methodology and most were underpinned by theories from innovation literature. The success factors identified for DiY laboratories include personal motivation and the desire to create a business, whilst their emergence was driven by the need for extra income, experimenting with new ideas and the pursuit of hobbies outside formal work settings. Key challenges faced by DiY laboratories include economic and marketing factors, especially access to finance to scale up their innovations. The strategies used by DiY laboratories to diffuse their innovations are social networking, partnerships with bigger tech firms and selling off their innovations to investors. The study outlines the implications for practitioners, entrepreneurs, and government, and makes recommendations.

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Do-it-yourself; DiY laboratories; innovation diffusion; digital innovation

1. Introduction

A do-it-yourself (DiY) laboratory is defined as 'a place where people "do stuff", create and tinker in a friendly, open, creative and collective atmosphere' (Meyer 2013). Although the DiY movement emerged in the 1950s and 1960s (Meyer and Vergnaud 2020), it has only attracted significant attention over the last two decades, as witnessed by the volume of literature on the subject. DiY labs may be located in people's backyards, garages, community spaces, warehouses, or other private but easily accessible spaces (Landrain et al. 2013; Seyfried, Pei, and Schmidt 2014). The characteristics of DiY include a highly informal set-up, low capital investment, absence of regulations, less intense competition, a lack of professional marketing personnel (Sarpong and Rawal 2020), and no documented commercialisation strategy. They contrast with innovation hubs or digital garages, representing more formal set-ups, access to funding from the government, regulatory and governance requirements, and access to a large market (Ng, Arndt, and Huang 2020). Existing research highlights a diversity of perspectives concerning DIY activities, but there is a clear

CONTACT Michael D. Dzandu dzandum@westminster.ac.uk Centre for Digital Business Research, Westminster Business School, University of Westminster, 35 Marylebone Road, London NW1 5LS, UK

distinction between these activities and those undertaken within the institutional model that is seen in corporate or university setting meaning that DiY can be seen as the informal and low end of the innovation chain (Galvin, Burton, and Nyuur 2020). When successfully scaled up, they offer new entrepreneurs, products, and service innovations typical of business organisations and capable of making a significant impact on society.

The interconnectivity of DiY labs terminologies suggests that it is multidisciplinary, bounded by open innovation (Chesbrough 2015), open science directed by citizens with a transdisciplinary research agenda and grounded in participatory research (You et al. 2020). The definition and characteristics of the DIY lab suggest that it is a movement (Ireland 2017; Landrain et al. 2013) and a business (Meissner et al. 2021; Wu and He 2020) that operates mainly in the informal sector, although it gradually metamorphoses into a formal business. Therefore, DiY labs are increasingly providing space for new inventions and innovation. Over the years, DiY labs have attracted institutions, academics, and government as viable testbeds for innovations. However, few studies explicitly provide a state-of-the-art summary of the purpose, context, methods, theories/models and strategies for innovation diffusion and commercialisation whilst assessing the implications of these for society and management. Thus, this study aims to provide a state-of-the-art review of DiY laboratories focusing on literature over the last two decades, when the diffusion of DiY laboratories across the world assumed significant proportions (Sarpong et al. 2020) and the subject began to attract the attention of academics and practitioners.

Despite the growth in the literature, there are limited studies that explicitly provides an account of the purpose, context, theories/models, and the methodologies used in studies on DiY laboratories. There are limited accounts of the factors driving the emergence of DiY laboratories and the challenges and success factors of DiY laboratories (e.g. Scheifele and Burkett 2016; Bell et al. 2014). Although an understanding of the strategies for diffusion of innovations and commercialisation methods of the products and services from DiY laboratories is necessary to assess their impact on society, there is a limited number of scholarly work that summarise these strategies. This study also responds to Sarpong and Liedong's (2021) call for a systematic review of the literature on 'the management and implications of DiY laboratories for innovation and society'. We propose that a systematic review of this area requires more rigorous research to widen the theoretical understanding of DiY labs for innovation and society. This study, therefore, provides a systematic literature account of the purpose, methods, context, models/theories, challenges, and strategies in the literature on DiY laboratories. The motivation for this study is to address the following research questions:

R1: What is the state-of-the-art literature on DiY laboratories with respect to the purpose, context, and methods used?

R2: What theories or models underpin current studies on DiY laboratories?

R3: What factors drive the emergence of DiY laboratories?

R4: How have the challenges to DiY laboratories been resolved, leading to their success?

R5: What strategies do DiY laboratories use to diffuse innovation and commercialisation?

We use a systematic literature review to examine the research questions. Our study complements earlier overviews of studies on DiY (e.g. Sarpong et al. 2020; Meyer 2021; Nascimento, Pereira, and Ghezzi 2014) by extending the scope to the research questions *R1-R5* and considering publications from the year 2000 up to February 2021. Whilst Nascimento, Pereira, and Ghezzi (2014) an annotated account of the transition from citizen science to do-it-yourself science, Ferretti (2019) provided a framework for examining the discourse on DIY science, and Meyer (2021) provided an overview of the history and the various practices of DIY biology. None of these studies focused on the DiY lab or specifically addressed the research questions pursued in this study. Our study examines the progress of research into DiY labs concerning the diffusion of innovation and commercialisation, and in so doing, propose research avenues that need further scrutiny. The rest of the paper is organised as

follows: first, we discuss the methods used for the systematic literature review. This is followed by the presentation of the results of the review on DiY laboratories. The next section of the paper examines the implications of the result for management and society. The conclusion highlights the limitations and areas for future research on DiY laboratories.

2. Method

The systematic literature review method (Kitchenham et al. 2009) was used. This involved the three-phase process of planning the review, conducting the review, and reporting the review (Tranfield, Denyer, and Smart 2003).

2.1 Planning the review

This phase of the study outlines the reasons for the review and review protocol development (Kitchenham 2004). This study aims to conduct a systematic literature review to identify theories and methods used in DiY labs, DiY labs' purposes and challenges, and strategies to diffuse innovation and commercialisation of DiY products and services. To address these research questions, we developed and implemented an initial review protocol by conducting a scoping study on DiY laboratories. The initial scoping was carried out on databases including the Web of Science, Scopus, JSTOR, IEEE Xplore, Association for Computing Machinery Digital Library and ASCE Library, using the search term 'DiY laboratories' to gauge the breadth of literature available for consideration. A decision on the inclusion and exclusion criteria was also reached at this stage.

2.2 Conducting the review

In conducting the review, we followed the five-step guidelines of Kitchenham (2004): identification of the research, selection of primary studies, quality assessment, data extraction and monitoring, and data synthesis.

2.2.1 Identification of the study

This study aims to understand the state-of-the-art literature on DiY laboratories by reviewing relevant and high-quality literature on the subject. Based on the themes in the call by Sarpong and Liedong (2021), this study focused on the purpose, context, method, theory/models, strategies for innovation diffusion and commercialisation and challenges of DiY labs.

2.2.2 Selection of primary studies

A literature search was conducted on the Scopus electronic database, selected for the study because of its wide scope (Hosseini et al. 2018). After several refinements, the following search query was used:

> TITLE-ABS-KEY (do AND it AND yourself AND laboratories) AND (LIMIT TO (LANGUAGE, 'English')) AND (LIMIT-TO (SRCTYPE,"j') OR LIMIT TO (SRCTYPE, 'p') OR LIMIT-TO (SRCTYPE, 'd')) AND (LIMIT-TO (PUBYEAR, 2021) OR … LIMIT-TO (PUBYEAR, 2002))

This search query yielded a total of 156 peer-reviewed journal papers. These were first reviewed independently by the two researchers for relevance. Aside from using the relevance ranking of the articles by the Scopus search engine, the researchers critically evaluated the content of each selected paper for evidence of DiY labs. Papers that merely mentioned or only made passing reference to DiY labs were deemed not relevant and excluded. Where there was disagreement on the inclusion/exclusion of a paper, a third person's opinion within the academic community was sought to help decide.

2.2.3 Quality assessment

The publications were assessed for quality using the inclusion/exclusion criteria. The quality of the papers was ensured by limiting the publications to peer-reviewed journal articles and conference papers published in the English language between 2000 and 2021. Case studies, dissertations, books, and trade journals that merely mentioned DiY in the text were excluded based on the suggestions of Webster and Watson (1992) that the best source materials for reviews are journals and conference proceedings, especially those with a reputation for quality (e.g. have impact factor and indexed in Scopus, etc.). This reduced the number of papers to 132, further reduced to 57 after excluding articles that appeared at the low end of the list of articles sorted by relevance to DiY labs. A summary of the journal publication is shown in Table 1 (Appendix A).

2.2.4 Data extraction and monitoring

At this stage, the final dataset on 57 journal articles and conference papers was exported from the Scopus database as a CSV file and opened in Microsoft Excel and NVivo for analysis. There were 18 fields of data for each of the selected articles, of which three were deleted as irrelevant for the final data synthesis. Available PDFs of the articles were then downloaded for data synthesis. Where the PDFs were not available, other sources such as ResearchGate, and academic and search engines such as Google Scholar and Google were utilised to find and download those articles. Further, authors of papers still unavailable were contacted through ResearchGate, LinkedIn and Google Scholar by following leads on their profiles and affiliations online. However, eight documents that could still not be found were excluded from the analysis. When the contents were analysed, another 20 documents were found not to have discussed DiY labs and were excluded; they had referred to 'DiY' and 'laboratories' as separate entities. The final number of relevant papers analysed was thus 29. Although this might be considered small, it is similar in number Sarpong et al. (2020). In addition, the Scopus database was periodically monitored for any new or late additions of papers on the topic by running the search term throughout authoring this paper until the time of submission.

2.2.5 Data synthesis

The actual data synthesis involved critical scrutiny of the selected papers for the study, the context or study setting, and the methodology used in each of the studies. The analysis also covered the type of models or theories that underpinned the studies, the challenges faced by the DiY laboratories and the success factors. In addition, evidence of the strategies used in diffusing the innovations from DiY laboratories as well as methods of commercialisation were explored. The outcome of the data synthesis is reported in the next section, in line with the suggestions of Kitchenham et al. (2009).

3. Results

The results of the study have been organised under key headings: purpose, context, and methods used, factors that drive the emergence of DiY labs, theories/models that underpin DiY labs, methodologies used and models that underlie DiY literature, the challenges and success factors of DiY, strategies use to diffuse DiY innovations and commercialisation. Of the final 29 publications analysed, 28 (96.5%) were journal articles, and 1 (3.5%) was a conference paper.

3.1 Purpose, context and methods used in studies on DiY laboratories

In this section, the findings on the purpose, context and methods used in studies on DiY laboratories (*R1*) are reported. The purpose of the studies reviewed was used to measure the scope of current literature on the labs. The breath of current studies includes the ecosystem and evolution of and demonstrations of various DiY products, opportunities, and limits of DiY labs, and their implications for science, technology, and innovation policy. The current studies have yielded key findings,

including DiY labs as alternative sources of innovation and a range of low-cost products made from and with readily available and inexpensive materials. The key findings also include the benefits and risk evaluation outcomes of DiY science, and the development of innovative products and solutions comparable with standard innovations developed in industry, universities, and innovation hubs. DiY labs have provided positive models for education and training and a unique blueprint for knowledge transfer from the grassroots to, potentially, commercialisation. Finally, whilst DiY biology has been classed as having gone through two phases, namely constitution (2008-2012); and maturation and autonomisation (from 2013 onwards) (Meyer and Vergnaud 2020), the general DiY labs literature has not. Future research could therefore explore the maturity of DiY labs to understand the distinct phases and challenges associated with each phase and how to overcome these.

Another objective of the study was to ascertain the context of DiY labs reported in current literature. The findings revealed six key areas of DiY lab settings: science and technology; biology/biotech; education; business management and entrepreneurship; IT security/software; and 'others.' The results showed that DiY labs operate mostly within the science/technology or biology/biotech contexts. This is not surprising, as the DiY movement seems to be dominated by technology innovators (Ng, Arndt, and Huang 2020). The need to overcome barriers such as prohibitive cost, regulatory requirements, governance, and bureaucracy, deemed especially by biology enthusiasts to stifle innovation, led to the DiY and open science movements. Although these barriers have somehow been overcome by democratisation, the consequences of risk to health and the environment (Wolinsky 2009; Sarpong and Rawal 2020) and threats of bioterrorism (Meyer and Vergnaud 2020) remain a critical concern of critics of DiY labs and governments.

There was limited evidence of DiY labs in the context of education, specifically in digital technology (Alía et al. 2019; Rowe et al. 2011), where the need to provide a platform for students to learn by experience and through experimentation seems paramount. This model of education could be extended to all technical courses and technology-based training where the lack of access to resources and formal laboratories creates a total disconnect between the theories taught to students and the practical aspects of these theories. Therefore, it is expected that DiY labs' success in the areas of biology and technology could be a use case to encourage other hobbyists to explore their innovative business management services in DiY labs. However, most of the business management domains are regulated by their professional bodies which do not seem to allow the experimentation and exploration of innovative ideas modelled on the DiY lab. Similarly, the limited evidence of DiY labs in the context of IT security and software development could be due to their being highly regulated and to the substantial risk associated with and implications of IT security breaches and software malfunction.

The analysis of current studies on DiY labs revealed the use of case studies as the dominant methodology, followed by the design and experiment method. This emphasised the significance of the case study approach as an appropriate tool for in-depth analysis of a phenomenon such as DiY labs. In addition, since most of the reports on DiY labs were science-based studies, practical methodologies such as design and experimentation were relevant. About a fifth of the papers analysed were literature reviews or employed mixed quantitative and qualitative methods. The least-used methodology was quantitative surveys. Therefore, quantitative studies that empirically measure and test the relationship between some activities and performance indices of DiY labs would provide new dimensions to research.

3.2 Models or theories used in studies on DiY laboratories

The review revealed a range of theories and models (*R2*) that underpin current studies on DiY laboratories, although most of the studies were not underpinned by any theory or model. However, of the few studies, the Theory of Ecosystems or Business Innovation Ecosystems was notable (Wu and He 2020). Ecosystem theories shed light on the key players within the DiY lab ecosystem and their interdependencies in an innovative ecosystem. A few studies were based on Value Theory, specifically, the Triple-Layered Business Model Canvas (TLBMC) and Co-design and Co-creation Theory,

where DiY labs are evaluated for their economic, environmental, and social values (Robazza et al. 2020; Meissner et al. 2021). The theories of ethical utilitarianism, deontology, and egoism (Rodgers et al. 2020) and Open Innovation Theory (Cheah, Yuen-Ping, and Shiyu 2020) were also relevant, as it is important to understand the benefits of DiY labs against the risk, hazards, ethical and other criticisms as a ground for abuse of standard innovation practices. The DiY lab aimed at breaking established business innovation barriers, reflected in the use of the Alternative Science Model and Displacement Theory and the Theory of Cognitive Adaptation (Vessal et al. 2021) to underpin some of the studies. However, the current studies only extended existing theories to DiY labs. There are thus opportunities for future researchers to generate new theories and models that would help consolidate and advance scholarship on the subject.

There was also evidence of some linked models used to support the discussion of the findings or proposed extensions to existing theories. These models include the Theory of Transformative Change, Theory of Constructionism (Sarpong et al. 2020) and the Entrepreneurial Event Model (Vessal et al. 2021), which were used to explain the drive and emergence of DiY labs in different settings. There was also mention of proposed models such as the Grand Bioterrorism Model, which helps assess the risk of DiY labs and funding models, although no specific funding models were mentioned in any of the current literature reviewed.

3.3 Factors driving the emergence of DiY laboratories and governance systems

The emergence of DiY labs (*R3*) appears to be driven by personal, community and resource-constraint challenges, economic returns, and the desire to democratise and diversify the sources of innovation. On the individual level, some were driven by the personal motivation to create some innovation or upscale their hobby to benefit society for self-actualisation. The demand for certain products and services lacking in the community provoked the innovation spirit in some enthusiasts and drove them to set up DiY labs. Some were also driven by their pursuit of sovereignty, creativity, passion, freedom, and developing leadership skills for personal and professional advancement. The lack of resources and access to state-of-the-art equipment for experimentation and innovation appears to have fuelled the desires of some to set up labs. Others were motivated by the possibility of economic gains by using inexpensive materials and applying cost-effective, practical methods. Certain life events (Vessal et al. 2021), such as unemployment, are known to drive entrepreneurs to set up labs for innovation (Harms et al. 2014), replicating the corporate settings they once worked in (Vessal et al. 2021). The setting up of some DiY labs was motivated by the need to widen access to research and innovation beyond academic laboratories for social inclusion and the benefit of society at the grassroots level.

The current literature on DiY labs was found to lack evidence on governance policy and regulations, and it was observed that most of the labs were autonomous or self-governed. However, there was some evidence of indirect governance and regulation through the labs' affiliation with institutions or advocacy groups such as DiYbio.org, Fab Lab networks, and hackerspaces.org (Cheah, Yuen-Ping, and Shiyu 2020; Alía et al. 2019). The general lack of governance and regulations of DiY labs confirmed the highly informal structures that characterise them; critics have raised concerns over risk and the consequences of ignoring governance and regulation policies, especially for fear of bioterrorism and negative environmental impact (Meyer and Vergnaud 2020). The call for laws, regulations, and procedures to validate the products and innovations from DiY labs and ensure compliance with risk, health, safety, ethical, security and sustainability requirements is not only relevant but necessary. However, such regulations and governance could be counterproductive such that it may eventually kill the spirit of innovation in society.

3.4 Challenges and success factors of DiY laboratories

Another objective of the study was to understand the challenges faced by DiY laboratories (*R4*) and some of their factors for success despite the challenges. The challenges include lack of access to

funding, regulatory demands, and limited resources for R&D and commercialisation (Beltagui, Sesis, and Stylos 2021; Rodgers et al. 2020). DiY labs are also faced with bureaucratic challenges that can stifle the process of innovation. Although laws, regulations and standards are necessary to help streamline the activities of manufacturers, the DiY labs perceive these as complex, leading to non-compliance. In addition, not only do DiY labs face the challenge of adapting their innovations to local contexts, but they also face difficulties in diffusing and commercialising their products. DiY labs also face difficulties such as exclusion and discrimination regarding access to funding and support by government and investment companies. Their practices are not uniform within and across sectors, and most do not subscribe to any code of governance. They lack clear business models, which may lead to a loss of focus and difficulty in realising the full potential of their innovations. DiY labs also face the challenge of exploitation by large businesses, sometimes leading to the loss of their innovations (Cheah, Yuen-Ping, and Shiyu 2020). The activities of DiY labs sometimes run contrary to community expectations of them, thereby resulting in a local conflict, while failing to enjoy the support of the public may affect the innovation process at every stage. At the individual level, entrepreneurs face their own personal and perceived challenges, such as managing the group dynamics and negotiating the norm and group cultures (Meyer and Vergnaud 2020).

However, despite the numerous challenges, the literature abounds in indicators and success factors of DiY labs. These include the sovereignty of users, fulfilment of personal motivation and personal development, social mobilisation and support, and avenues for inclusiveness through community participation and personal contextualisation of innovations; the availability and maximisation of the value of inexpensive equipment to deliver low-cost products, services and solutions; and breaking down barriers to innovation, such as allowing the involvement of young people, even 10–12 year-olds, in a DiY lab community project. The DiY labs have been successful in organising healthy competition among their members and financial mobilisation through crowdfunding. Their success is also reflected in their ability to create open spaces that have enhanced the entrepreneurship spirit in technology enthusiasts and provided avenues for leadership, education, and an authentic environment for experimentation, continuous improvement, and learning. Some DiY labs serve as intermediaries by helping to transform 'technology-centred into socio-centred DiY labs' (Lhoste 2020; Vessal et al. 2021). Another indicator of the success of DiY labs is their role as agents of change with the capacity to inspire communities and institutions to deliver local solutions to community problems such as digital technologies (Ng, Arndt, and Huang 2020). DiY labs have successfully created loyal users who freely share knowledge through their networking activities (Chrysostome 2010). They have been successful in breaking down barriers, for example, by providing access to alternative equipment and raw materials outside institutional labs. DiY labs make it possible for technology enthusiasts to start a company. The data from the study shows that DiY labs serve as alternative sources of research and affordable and hands-on education, which should long continue to be a source, if not the major source, of innovation.

3.5 Strategies for innovation diffusion and commercialisation

The current literature on DiY labs is deficient in strategies for innovation diffusion and commercialisation (*R5*). Ng, Arndt, and Huang (2020) called for future studies to explore the strategies used to diffuse innovations and evolving strategies in maturing markets. The data from this study revealed that most DiY labs adopt an open lab/science platform strategy to diffuse their innovations, aiming to demystify and democratise their inventions through open source and sharing of their innovations at the grassroots level. The use of online platforms like Kickstarter helps some DiY labs to leverage the power and reach of the Internet to spread their innovations beyond the borders of their communities and country. Technology enthusiasts who nurture and develop their innovative ideas from DiY labs rely on social networks to diffuse their innovations, usually within their local communities, through informal promotional channels such as word-of-mouth. Some DiY labs diffuse their innovations through customisation and nurturing their customers' unique demands and taste at

meetings (Ng, Arndt, and Huang 2020). Personal promotion, intuition and drive strategy, based on the locus of control as used in entrepreneurship, is also used by some DiY labs to diffuse their innovations. There was, however, evidence to suggest that innovations from DiY labs hardly remain in service long enough for diffusion beyond the local community.

It was noted that innovations from DiY labs tend to be prised away from their origins or sold to larger businesses and investors who have logistical, financial, and professional knowledge and a large market for the diffusion of the innovations. Large businesses tend to be exploitative by incentivising their staff to join local DiY labs (Sarpong and Rawal 2020) and bring back their ideas. This raises the question of unethical behaviour by large companies and privacy concerns leading to the loss of innovative ideas and inventions. Another strategy for the diffusion of innovations from DiY labs is mergers and acquisitions. Market leaders acquire and integrate these innovations into their ecosystems as complimentary products to kill off competition from the labs. Few labs have adopted the strategy of continuous innovation to compete with larger companies and avoid being controlled by the market leaders (Ng, Arndt, and Huang 2020). Government policy to control the abuse would be welcome to protect DiY innovators, providing a level playing field devoid of monopolistic tendencies whilst encouraging the growth of the otherwise informal sector under which DiY labs operate. This would help protect the DiY lab community and create more SMEs capable of contributing to the socio-economic development of society.

The lack of studies on the commercialisation of the innovations of DiY labs is amplified by Meyer and Vergnaud (2020). They called for future studies to examine in detail the strategies and processes of the innovation journey from ideation to commercialisation of DiY products. The data revealed that whilst some innovations from DiY labs do not make it to the commercialisation stage, others are content to sell their inventions to a niche market, especially within their local community (Scheifele and Burkett 2016). In another commercialisation model, some labs make their innovations freely available as open-source knowledge, including through online portals such as the Mendeley data repository. Another commercialisation model is the sharing model, built on sharing economy logic, where interested parties, investors, and members of the DiY labs themselves contribute to and share in the commercialisation of the innovation. In technology-driven collaborative product innovation (Sarpong et al. 2020), the labs rely on or collaborate with incubators, leading industrial firms and universities for commercialisation, continuous research and development, training, and education. There is, however, evidence to suggest some degree of economic exploitation of the intellectual capital and property of the DiY labs by large and well-established firms (Ng, Arndt, and Huang 2020). Some labs used the alternative funding strategy to receive funding from government or financing institutions to commercialise and promote their innovations to expand their market, including through exports and internationalisation. With these limitations in mind, the next two sections present a discussion and implications of the study.

4. Discussion and implications

This study systematically reviewed the literature on DiY laboratories over the last two decades to provide a state-of-the-art picture to help understand the breadth of current knowledge on DiY labs and drive future research agenda. The results showed that the current literature on DiY labs focuses on understanding the intrinsic motivation of individual technology enthusiasts for pursuing innovations in highly informal settings such as garages, libraries, town halls and kitchens. Therefore, there is a gap in the current literature on what the extrinsic motivation of DiY labs enthusiasts is and how these tie in with the values and expectations of the community where DiY labs are established. Furthermore, an understanding of the socio-economic exigencies and personal drivers in the pursuit of innovation in DiY labs against the risk, ethics and security threats posed by operating some DiY labs that are highly unregulated, ungoverned, and uninsured would be worthwhile. In addition, it would be useful for future studies to evaluate the socio-economic impact of DiY labs on national economic development as a way of understanding their impact on society and contribution to

economic empowerment. It would also be worth exploring whether DiY labs are sustainable and their impact on equality, diversity, and inclusion. Another valuable study area would be to understand whether DiY labs are avenues for marginalisation and a tool for promoting the digital divide and genderisation of Science, Technology, Engineering and Mathematics (STEM) in society.

An essential feature in academic scholarship is the need to either underpin a study with a theory or, better still, make a new theoretical contribution. Therefore, the literature on DiY labs was scrutinised for evidence of theory or models as the foundation of these studies. The findings suggest that the DiY lab is more of a science-based setup, largely not underpinned by any theory or model. The limited evidence of theories/models were mostly business models. This was, however, not surprising since most of the studies were either case studies or review papers. Therefore, there is a need for more empirical studies that test current business and technology models. For example, studies that explore technology diffusion and acceptance; game theory; technology, organisation and environment (TOE) models, financial models, marketing theory, strategy and alignment models, and sustainability models are worth pursuing, whilst explicitly developing new theories/models driven by DiY labs.

DiY labs serve as an avenue for democratising the scientific innovation ecosystem by providing opportunities for the 'have not' technology entrepreneurs and helping to bridge the gap with the well-endowed business incubators. DiY labs remove innovation inertia and help promote inclusivity (Vessal et al. 2021) and diversity in innovation. DiY labs have the potential to break the monopoly of large businesses and science and innovation hubs that enjoy government support and have access to funding, professional knowledge, and carefully planned strategies for promoting, commercialising, and monetising their technological innovations. The success of DiY labs in breaking the entry barriers to business start-ups can serve as a model for other sectors and disciplines, such as marketing, finance, and supply chain, to pursue DiY business start-ups. This would lead to an upsurge in SMEs across economies, which would improve socio-economic development across the world and thus accelerate the shift from the technology-led DiY labs to social-led labs (Vessal et al. 2021; Lhoste 2020).

5. Implications for innovation and society

Our results revealed a growing number of DiY labs experimenting with ideas, collaborating, and producing innovative products and services. They are increasingly becoming the third pillar of innovation drivers, the first and second being industry and academic institutions. As reported in the findings, DiY labs can co-exist within the wider ecosystems of industry and academic institutions, contributing to innovation and the welfare of society, as reported by Wulandhari et al. (2021) and Wu and He (2020). We also noted that the welfare of society in terms of knowledge generation or value creation is evident in existing research, from emerging African nations (e.g. Atiase, Kolade, and Liedong 2020) to highly developed Singapore (e.g. Cheah, Yuen-Ping, and Shiyu 2020). It is a growing phenomenon that can find solutions in a short amount of time, as evident during the Covid-19 pandemic. However, the recognition, contribution and governance of DiY labs are yet to be integrated into government policy in both developed and developing economies.

6. Implications for theory and research

In an attempt to systematically review and synthesise the literature on DiY labs, and in responding to the call of Sarpong and Liedong (2021), we have identified the key theories and methods used to study DiY labs' innovation and reported the purpose, research context and methods, challenges, success factors and diffusion strategies. Based on our results, we argue that the further development of DiY labs for innovation and society requires more rigorous research from qualitative and quantitative perspectives to widen the theoretical understanding of DiY labs for innovation. Future research could shed light on the management of DiY labs and accelerating the innovation

process from DiY labs through marketing theories and commercialisation models. This could also provide an alternative to current innovation practices, where many large and heavily financed innovation projects are deemed to have failed. Future studies could therefore focus on financial models and sustainability of innovations from DiY labs.

7. Conclusion

This research aimed to understand the state-of-the-art literature on DiY labs with regards to their purpose, context, theories, and methods used, success factors, strategies implemented and challenges. By reviewing 29 published papers from the last two decades, the study answered five research questions (*R1-R5);* and is among a few papers to investigate the DiY labs literature in terms of research context, purpose, methods used, strategies adopted and challenges faced by DiY labs. The study outcomes re-emphasise the significant role of DiY labs in breaking the monopoly of traditional government-supported technology start-ups. In addition, the growth of the DiY movement needs government supports. The institutionalisation of regulatory policy and governance framework to support the activities of DiY labs would go a long way to mitigate the risks, security and ethical concerns associated with the operations of DiY labs. The implications of the results for innovation management and society have been highlighted, while the implications for theory discussed could provide future research directions for scholars.

This study considered only peer-reviewed journals and conference papers published in English and may have missed papers published in other outlets such as books and trade journals and in other languages. There is little evidence from the papers reviewed to suggest that external factors, particularly the environment, opportunities, social needs and demands of society, trigger these technology enthusiasts to embark on the journey of innovation in DiY labs (Shane and Venkataraman 2000; Vessal et al. 2021). However, it is also noted that unexpected events, such as the current Covid-19 pandemic, have created opportunities for both traditional businesses within formal sectors such as innovation hubs and DiY labs in the informal sector to rally together to create various innovative solutions for producing facemasks, testing equipment, face shields and many other products. Therefore, future studies could expand the search scope with reasonable justification to include other sources of information such as pandemics. Even though Scopus has a larger coverage than other electronic databases (Hosseini et al. 2018), future studies could extend the data sources to include other databases such as Web of Science and JSTOR.

Disclosure statement

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Notes on contributors

Michael D. Dzandu (PhD) is a Research Fellow in Digital Business at the Centre for Digital Business Research, Westminster Business School, University of Westminster, London, UK. His research interest spans technology, culture and human behaviour. His current research activities are in the areas of ontology, data and information modelling, digital twins and Industry 4.0 technologies.

Buddhi Pathak (PhD) is a Lecturer in Strategic Management at Bristol Business School, the University of West of England, UK. His research investigates issues around why firms exist and how their value creation process implies a broader business and societal ecosystems; with a specific emphasis on culture, knowledge, innovation and the impact of emerging technologies.

ORCID

Michael D. Dzandu http://orcid.org/0000-0002-3486-7150
Buddhi Pathak http://orcid.org/0000-0001-9801-642X

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Appendix A

Table 1. Summary of the journal publications based on relevance and quality criteria.

Paper	Authors	Title	Year
1	Meissner D., Sarpong D., Ofosu G., Botchie D.	The rise of do-it-yourself (DiY) laboratories: Implications for science, technology, and innovation (STI) policy	2021
2	Rezaee Vessal S., Partouche-Sebban J., Scuotto V., Maalaoui A.	Overcoming stressful life events at do-it-yourself (DIY) laboratories. A new trailblazing career for disadvantaged entrepreneurs	2021
3	Riihiaho K.A., Eskelinen M.A., Pölönen I.	A do-it-yourself hyperspectral imager brought to practice with open-source python	2021
4	Weib M., Angerbauer K., Voit A., Schwarzl M., Sedlmair M., Mayer S.	Revisited: Comparison of Empirical Methods to Evaluate Visualizations Supporting Crafting and Assembly Purposes	2021
5	Ng W., Arndt F., Huang T.Y.	Do-It-yourself laboratories as integration-based ecosystems	2020
6	Lhoste E.F.	Can do-it-yourself laboratories open up the science, technology, and innovation research system to civil society?	2020
7	Rodgers W., Al Shammakhi B.N., Jeaneth J., Wincent J., Adams K.	DIY Entrepreneurship: a decision-pathway framework for ethical thought structures	2020
8	Wu Q., He Q.	DIY Laboratories and business innovation ecosystems: The case of pharmaceutical industry	2020
9	Landrain T., Meyer M., Perez A.M., Sussan R.	Do-it-yourself biology: Challenges and promises for an open science and technology movement	2013
10	Meyer M., Vergnaud F.	The rise of biohacking: Tracing the emergence and evolution of DIY biology through online discussions	2020
11	You W., Chen W., Agyapong M., Mordi C.	The business model of Do-It-Yourself (DIY) laboratories – A triple-layered perspective	2020
12	Nazarious M.I., Mathanlal T., Zorzano M.-P., Martin-Torres J.	Pressure Optimized PowEred Respirator (PROPER): A miniaturized wearable cleanroom and biosafety system for aerially transmitted viral infections such as COVID-19	2020
13	Nedbal J., Gao L., Suhling K.	Bottom-illuminated orbital shaker for microalgae cultivation	2020
14	Fritzsche A.	Making without fabrication: Do-it-yourself activities for IT security in an open lab	2020
15	Sarpong D., Ofosu G., Botchie D., Clear F.	Do-it-yourself (DiY) science: The proliferation, relevance and concerns	2020

(*Continued*)

Table 1. Continued.

Paper	Authors	Title	Year
16	Robazza P., Longo D., Bortoli G., Alese G., Boeri A.	DIY urbanism as a tool of urban regeneration. Two cases in comparison	2020
17	Diaz-de-Quijano, D., Stratmann, C. N., Berger, S. A.	DIY enzyme labelled fluorescence alcohol (ELFA) standard production protocol to quantify single-cell phosphatase activity (SCPA)of microplankton	2020
18	Cox S., Leigh N.J., Vanderbush T.S., Choo E., Goniewicz M.L., Dawkins L.	An exploration into "do-it-yourself" (DIY)e-liquid mixing: Users' motivations, practices and product laboratory analysis	2019
19	Alía C., Ocaña R., Caja J., Maresca P., Moreno-Díaz C., Narbón J.J.	Use of open manufacturing laboratories (Fab Labs) as a new trend in engineering education	2019
20	Atiase, V. Y., Kolade, O., Liedong, T. A.	The emergence and strategy of tech hubs in Africa: Implications for knowledge production and value creation	2020
21	Wulandhari, N., B., Mishra, N., Dora, M. and Samuel, F. W.	Understanding rural Do-It-Yourself science through social learning in communities of practice	2021
22	Beltagui, A., Sesis, A., and Stylos, N.	A bricolage perspective on democratising innovation: The case of 3D printing in makerspaces	2021
23	Galvin, P., Burton, N., Nyuur, R.	Leveraging inter-industry spillovers through DIY laboratories: entrepreneurship and innovation in the global bicycle industry	2020
24	Rowe A.A., Bonham A.J., White R.J., Zimmer M.P., Yadgar R.J., Hobza T.M., Honea J.W., Ben-Yaacov I., Plaxco K.W.	Cheapstat: An open-source, "do-it-yourself" potentiostat for analytical and educational applications	2011
25	Yoon J., Vonortas N.S., Han S.	Do-It-Yourself laboratories and attitude toward use: The effects of self-efficacy and the perception of security and privacy	2020
26	CHEAH S.L.-Y., HO Y.-P., LI S.	How the effect of opportunity discovery on innovation outcome differs between DIY laboratories and public research institutes: The role of industry turbulence and knowledge generation in the case of Singapore	2020
27	Ferretti, F. (2019)	Mapping do-it-yourself science.	2019
28	Scheifele, L.Z., Burkett, T.	The First Three Years of a Community Lab: lessons Learned and Ways Forward.	2016
29	Bell, F., Fletcher, G., Greenhill, A., Griffiths, M., & McLean, R.	Making MadLab: A creative space for innovation and creating prototypes.	2014